

# Optical Properties of Cooling Flow Central Cluster Ellipticals

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**Abstract.** Central cluster galaxies in cooling flows show the signatures of gaseous accretion and ongoing star formation at rates ranging between  $\sim 1 - 100 \text{ M}_\odot \text{ yr}^{-1}$ . Their blue morphologies usually reflect the low net angular momentum content of the  $T < 10^4 \text{ K}$  gas from which the accretion population formed, and the effects of interactions between the cool gas and their FR I radio sources. For example, there is strong evidence that star formation is being triggered, in part, by interactions between the  $T < 10^4 \text{ K}$  gas and the radio sources in some objects. Disk star formation on kiloparsec scales is rare in cooling flows. The optically determined star formation rates, assuming the Local initial mass function (IMF), are typically factors of  $10 - 100$  smaller than the cooling rates determined from X-ray observations, and signatures of the remaining material have not been identified outside of the X-ray band. The IMF is poorly understood in cooling flows; most of the cooling material may be deposited in low-mass stars or some other form of dark matter. Continued study of the interactions between radio sources and the intercluster medium will further our understanding of how elliptical galaxies, particularly radio ellipticals in the early universe, evolve.

## 1. Introduction

Roughly half of the clusters that have been detected with X-ray telescopes contain bright, centrally concentrated X-ray emission from  $\sim 10^7 \text{ K}$  gas that may be cooling from the hot phase at rates of  $\dot{m}_{CF} \sim L_x T^{-1} \sim 10 - 1000 \text{ M}_\odot \text{ yr}^{-1}$  (Fabian 1994). The cool material should settle to the center of the cluster and accrete onto the central cluster elliptical galaxy, where it will collect in molecular and neutral atomic gas clouds and eventually form stars. Stars forming at rates comparable to the cooling rates with a Local, disk-like IMF would render the central cluster galaxies brighter and bluer than normal ellipticals, and would be capable of producing large centrally dominant elliptical galaxies (CDGs) if star formation continued at rates of  $\sim 100 \text{ M}_\odot \text{ yr}^{-1}$  over the lifetimes of the clusters,  $\sim 10 \text{ Gyr}$ . Optical, infrared, and radio spectral line surveys of CDGs in cooling flows do indeed indicate enhanced levels of  $< 10^4 \text{ K}$  gas and star formation. However, the inferred star formation rates are much smaller (e.g.  $< 1 - 10\%$ ) than the cooling rates, and the amounts of detected cold gas can only account for  $\lesssim 10^8 \text{ yr}$  of accumulated material. The discrepancy between the cooling

rates determined with X-ray observations and the detected accreted mass is the so called “cooling flow problem.” Although the missing elements of this problem have not been identified conclusively, cluster cooling flow CDGs often have remarkable properties that bear on several important issues in astrophysics, including the formation and evolution of galaxies and radio sources in clusters, accretion dynamics in ellipticals, the nature of baryonic dark matter in clusters, and the suitability of CDGs as standard candles. This article addresses the first three of these topics from the aspects of optical imaging and spectroscopy.

## 2. Evidence for Accretion-Fueled Star Formation in Cooling Flows

Several studies have shown that the spectral energy distributions of CDGs in the wavelength range  $\lambda\lambda 3600 - 5000\text{\AA}$  exhibit continuum excesses and nebular line emission whose strengths increase with increasing  $\dot{m}_{CF}$  (Hu et al. 1985; Johnstone et al. 1987; McNamara & O’Connell 1989; Crawford & Fabian 1993; Allen 1995; Cardiel et al. 1995). The color excesses have amplitudes in  $U - B$  ranging from the detection limit of  $\sim 0.1$  magnitude to  $\gtrsim 1$  magnitude, and the accretion populations contribute  $\sim 10 - 70\%$  of the total light in the anomalously blue regions at U. Both the continuum excesses and the nebular emission are often spatially extended over the inner 5-30 kiloparsecs of the CDGs (McNamara & O’Connell 1993; Heckman 1981; Cowie et al. 1983; Heckman et al. 1989; Baum 1992; Donahue & Voit, this conference). In addition, H I has been detected in absorption against the radio continua of several CDGs in large cooling flows (O’Dea et al. 1995; O’Dea, this conference), and molecular gas has been detected in the CO feature in Perseus (Lazareff et al. 1989) and in the  $2.1\mu$   $\text{H}_2$  feature in essentially all of the large cooling flows with strong nebular line emission (Elston & Maloney 1996; Jaffe & Bremer 1996). These properties, which are atypical of CDGs outside of cooling flows, indicate abnormally large levels of cold gas and star formation in the centers of cooling flow CDGs.

$U - B$  color excesses in the central  $\sim 5$  kiloparsecs of CDGs in cooling flows, denoted  $\delta(U - B)_{\text{nuc}}$ , are plotted against the cooling rate of the hot gas derived from X-ray observations in Figure 1. The color excesses are plotted with respect to the mean for non-accreting template elliptical galaxies such that a negative excess indicates a bluer color. The optical data are taken from the sources cited above, and the X-ray data are mostly from Arnaud (1988). The  $U - B$  color was chosen because it is commonly available and includes the U-band, which is most sensitive to warm populations. Some color excesses were estimated from data in other bands and their errors may be  $\gtrsim 0.2$  magnitude, but most have errors  $\lesssim 0.1$  magnitude. The errors on the accretion rates are formally a factor of 2, but systematic errors could be larger. A trend for increasingly large blue color excesses with increasing cooling rate is seen in Figure 1. CDGs in clusters with  $\dot{m}_{CF} \lesssim 50 \text{ M}_\odot \text{ yr}^{-1}$  rarely show significant anomalies. M87’s ( $\dot{m}_{CF} \sim 30 \text{ M}_\odot \text{ yr}^{-1}$ ) blue synchrotron nucleus and jet is one exception. CDGs in clusters with  $\dot{m}_{CF} \gtrsim 200 \text{ M}_\odot \text{ yr}^{-1}$  show strong color excesses which often extend over the inner 5-30 kiloparsecs of the CDGs. The blue excesses in the moderate accretors ( $\dot{m}_{CF} \lesssim 200 \text{ M}_\odot \text{ yr}^{-1}$ ) are often unresolved from the ground (e.g. A2052), and may be associated with weak AGN. Dust features are present in at least half of the galaxies observed (McNamara & O’Connell 1992; 1993;

McNamara et al. 1996a; Pinkney et al. 1996). This trend makes a strong case for star formation fueled by accretion from cooling flows. Tidally induced accretion, ram pressure accretion, and mergers may affect this trend, although at first blush one would expect these effects to erase the trend.

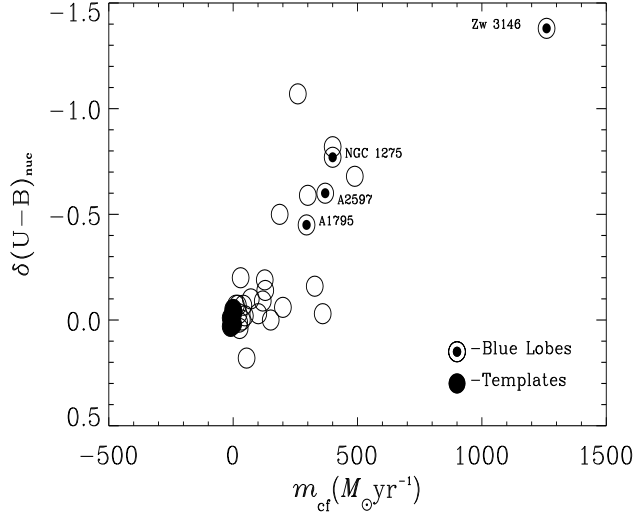


Figure 1: Correlation between central  $U - B$  continuum color excess and total cooling rate.

### 3. Star Formation Rates

Although the correlation in Figure 1 can be viewed as a predictive success of the cooling flow interpretation, one's enthusiasm should be tempered by the theory's incompleteness. While roughly half of the gas accreted within the extended blue regions (assuming  $\dot{m}(r) \propto r$ , see Fabian 1994) can be accounted for, only a few percent or less of the *total* mass of the gas cooling throughout the cooling region is found to be forming stars with the Local IMF. Furthermore, the optical properties of some CDGs in clusters with large cooling rates are normal (e.g. A2029). The star formation rates are determined in general as  $\dot{S} = M_{\text{lum}} t^{-1}$ . The luminosity mass is defined as  $M_{\text{lum}} = f_V L_V \Upsilon$ , where  $f$  is the fraction of the total luminosity in a given passband (V for example) contributed by the accretion population, and  $\Upsilon$  is the mass-to-light ratio of the accretion population. The age of the accretion population,  $t$ , is in general poorly known and is usually taken to be the typical age of a flow  $\sim \text{Gyr}$ .  $\Upsilon$  is taken from stellar population models that match the assumed age and physical conditions of the flow. The star formation rates determined in this manner are generally a few to a few tens of solar masses per year (McNamara & O'Connell 1989; 1993), compared to accretion rates of a few tens to several hundred solar masses per year. These star formation rates are in reasonably good agreement with those estimated using Balmer emission (within a factor of 2), indicating that the stellar continuum of the accretion population may be an important heat source for the nebular

emission (McNamara & O’Connell 1989). This has been difficult to understand because emission line spectra seem to be modeled better by shock ionization (Kent & Sargent 1979), irradiation from the condensing gas (Donahue & Voit 1991), or the turbulent mixing of hot and cold phase gas at the surfaces of cold clouds (Crawford & Fabian 1992), rather than emission from classical H II regions. In all likelihood there are several heating mechanisms (Baum 1992; Fabian 1994), but stellar photoionization is probably among the most significant (Donahue & Voit, Cardiel, this conference).

There is growing evidence, as I discuss below, that a burst mode of star formation may be significant, which would add uncertainty to the continuous rates. In addition, the presence of significant amounts of dust may lead to underestimated star formation rates (Allen 1995). The sink for the remaining accreted matter is unlikely to be cold gas, as  $< 10^9 M_\odot$  of gas with  $T < 10^4$  K has been detected outside of the X-ray regime (Voit & Donahue 1995; O’Dea, this conference). The remaining mass may be deposited in low-mass stars forming with an unusual IMF (Kroupa & Gilmore 1994; Schombert et al. 1993; Sarazin & O’Connell 1983) or some other form of dark matter. It is quite possible that the cooling rates have been overestimated to poorly understood gas physics. However, cooling at levels of several to several tens of solar masses per year in the largest accretors is consistent with the optical data. *AXAF* will provide important new observations with which to address this issue.

#### 4. Structure in Cooling Flow Central Cluster Galaxies

The star formation histories of CDGs over the past several hundred Myr, and the dynamical state of the accreting gas are imprinted on their surface brightness distributions and color structure. U-band imaging is most effective for studying the extended, blue stellar populations and nuclear AGN light, while being relatively insensitive to the red background population. The U-band’s sensitivity to blue continuum is somewhat limited by the [O II] $\lambda 3727$  emission feature, but becomes a less serious problem in galaxies at  $z \gtrsim 0.05$ , as the emission marches out of the U passband in the laboratory reference frame. Galaxies are faint at U, so 4m-class telescopes are required to study CDGs in detail, and the number of well-imaged galaxies is limited. I will focus on what we have learned from the best observed objects.

Cooling flow CDGs show a variety of blue structure. Four blue morphological types ordered by decreasing geometrical simplicity can be broadly defined: 1. unresolved point source, 2. disk, 3. lobe, 4. irregular–amorphous. These morphological types, shown schematically in Figure 2, largely reflect the level of star formation, the angular momentum state of the accreting gas from which stars are forming, and the physical relationships between gaseous phases—the radio plasma in particular—and star formation. Type 1 galaxies contain unresolved blue nuclei and nebular line emission. Their color excesses are modest, being one or two tenths of a magnitude in  $\delta(U - B)$ , and they tend to occur in CDGs with modest accretion rates of  $\lesssim 200 M_\odot \text{ yr}^{-1}$ . Their nebular luminosities of  $\sim 10^{41} \text{ ergs s}^{-1}$  are factors of several to ten smaller than those in the largest cooling flows (Heckman et al. 1989), and their color excesses signal either modest nuclear starbursts and/or weak AGN. Typical objects in this class are

the CDGs in A2052 and A2199. Type 2 CDGs contain disks of gas and young stars in rotation about the nucleus. The archetype, Hydra A, contains a young, blue stellar population that is confined to a  $\simeq 10$  kiloparsec disk of neutral and ionized hydrogen and molecular gas. The Type 2 morphology reflects a high angular momentum state of the accreted gas. Type 2s are rare in cooling flows, but not in the general population of radio galaxies (Tadhunter et al. 1989). Type 3, blue lobe CDGs are characterized by bright, blue lobes of optical continuum located several kiloparsecs from the nucleus. The best studied cases, A1795 and A2597, have radio emission that is coincident with their optical lobes (McNamara & O’Connell 1993). The lobes are surrounded by nebular line emission with disordered velocities, suggesting a low net angular momentum state (Heckman et al. 1989). Type 4, irregular–amorphous, encompasses most objects. The gas velocities are again disordered (except perhaps close to the nucleus) reflecting a low net angular momentum state. As we shall see below, the blue lobes in Type 3s are probably short lived and should evolve rapidly into an amorphous, Type 4 morphology.

#### Blue Morphological Types

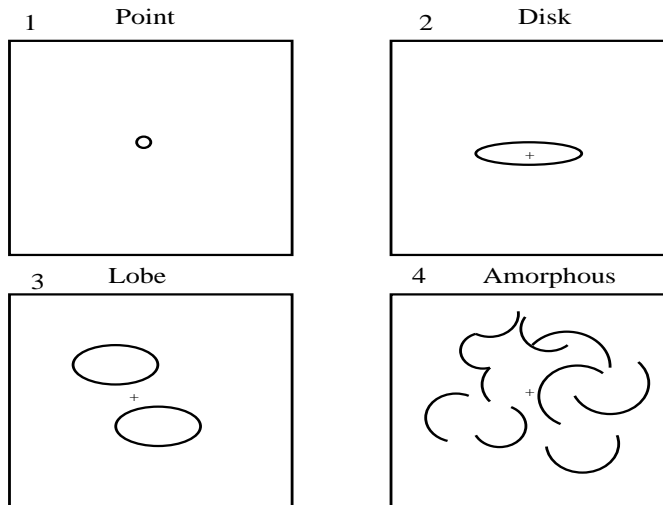


Figure 2: The blue morphological types found in cooling flows.

### 5. Interactions Between the Radio Source and Gaseous Medium

The A1795 CDG, at redshift  $z = 0.06$ , is the archetype Type 3, blue lobe galaxy (Figure 3). A1795 and A2597 ( $z = 0.08$ ) harbor bright, blue lobes of optical continuum along the edges of their radio lobes (McNamara & O’Connell 1993; Sarazin et al. 1995; McNamara et al. 1996a,c). The lobes are surrounded by a diffuse, abnormally blue population. A1795’s FR I radio source is  $\sim 10$  kiloparsecs in size and its luminosity is  $L_{\text{radio}} \simeq 9 \times 10^{41} \text{ ergs s}^{-1}$  (van Breugel et al. 1984). The radio jets emerge from the nucleus with a north-west, south-east orientation and extend several kiloparsecs into the galaxy before bending abruptly at right angles and inflating into radio lobes at the location of the

blue optical lobes (Figure 3). The jets were presumably deflected by cold, dense clouds associated with the dust lane. The optical lobes are resolved into discrete regions along radio lobe boundaries in V and R HST images (McNamara et al. 1996a; Pinkney et al. 1996). The central 20–30 kiloparsec region is embedded in luminous,  $L(\text{H}\alpha) \sim 10^{42} \text{ ergs s}^{-1}$ , nebular line emission (Heckman et al. 1989). A2597 has similar properties (Figure 4).

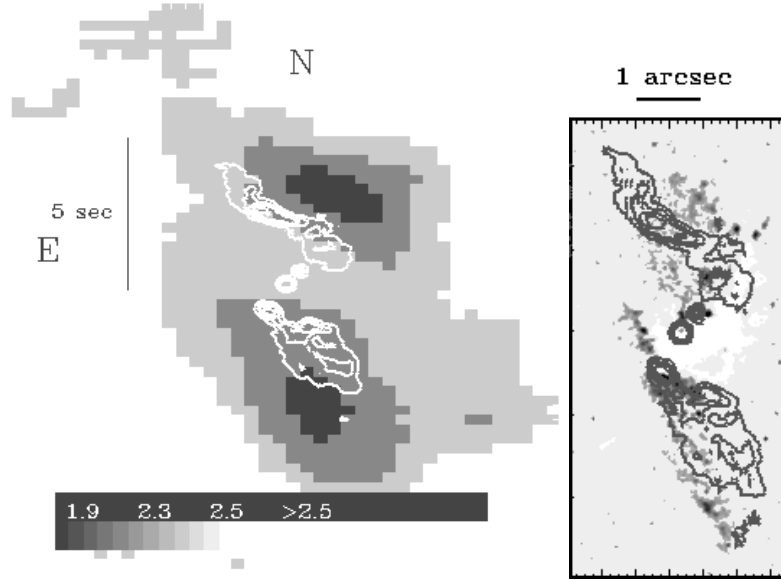


Figure 3: (Left) Ground-based  $U - I$  color map of A1795 showing the blue lobes (greyscale; 2 arcsec resolution) along the 3.6 cm radio lobes (contours; 0.2 arcsec resolution)[McNamara & O’Connell 1993]. (Right) HST image in V+R of the same region after subtracting a model for the galactic background. The white region along the jet is the dust lane (McNamara et al. 1996a).

The discovery of the blue lobes in A1795 and A2597 (McNamara & O’Connell 1993) prompted several groups to suggest that the lobes were scattered light from a misdirected, anisotropically emitting AGN (Sarazin & Wise 1993; Crawford & Fabian 1993; Murphy & Chernoff 1993). This model predicts that the lobe light should be highly polarized. However, a recent polarization measurement of A1795’s lobes in the U-band resulted in an upper limit of less than 7% to the degree of polarization, which essentially excluded the scattering model (McNamara et al. 1996c). The absence of a detailed correspondence between the radio lobes and the optical lobes excludes synchrotron or inverse Compton scattering as the emission mechanism. Finally, the HST image (Figure 3) clearly shows what appear to be blue star clusters along the edges of the radio lobes, rendering this object perhaps the most convincing case for radio-triggered star formation. The probable age of the radio source in A1795 based on synchrotron losses is several to ten Myr (van Breugel et al. 1984). There is no evidence for rotationally supported gas out of which the lobes formed, so they should fall into the center of the galaxy in less than the free-fall timescale of  $\sim 40$  Myr. The close spatial correlation between the radio and optical lobes shows that the

stars have not fallen significant distances from their birthsites, implying an age of less than  $\sim 10$  Myr. Recall earlier suggestions that star formation in cooling flows may occur with unusual IMFs that are depleted in massive stars relative to low-mass stars, or possibly truncated at the highest masses (see O’Connell & McNamara 1989 for a discussion). This dynamical constraint on the lobe population age should limit the range of physically plausible stellar population models for A1795’s lobes. A comparison between  $\sim 10$  Myr old burst population model colors and HST photometry of the knots along the radio lobes in the U and UV, after correcting for internal extinction, should be sensitive to the IMF, in particular to an upper mass truncation of stars more massive than  $\sim B5V$ .

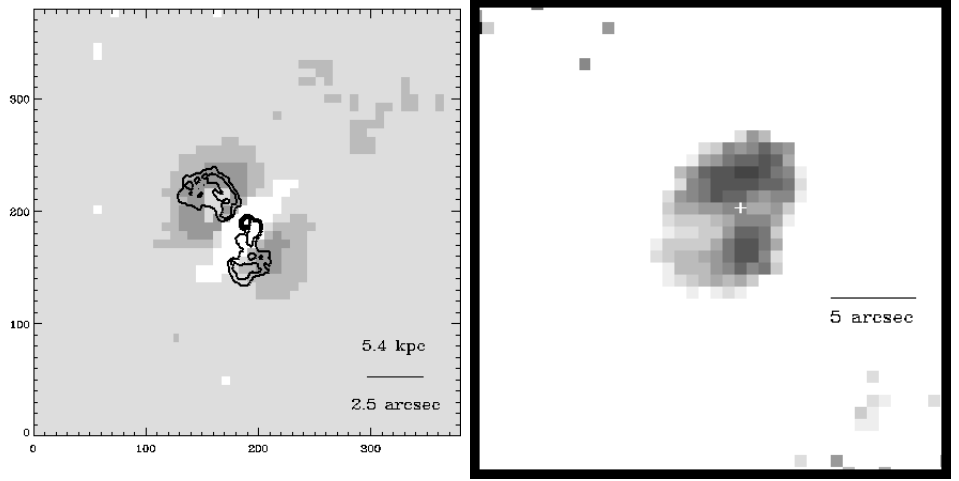


Figure 4: (Left) Emission-line-free Strömgren b-band image of the lobes in A2597 (greyscale) after subtracting a background model galaxy. The 8.4 GHz radio map (contours) is superposed. A dust lane bisects the nucleus at the location of the radio core. The reversed greyscale (darker for emission; lighter for absorption) is “wrapped” in the brightest part of the northern lobe for clarity (Sarazin et al. 1995; McNamara & O’Connell 1993). (Right)  $U - R$  color map of the distant, blue lobe galaxy in the  $z = 0.29$  cluster Zw3146. The restframe colors correspond to mid-UV–V. The intermediate passbands avoid prominent emission lines. The darkest regions are  $\sim 2$  magnitudes bluer than normal and are located a few arcsec off the nucleus in a north-south orientation. The “+” indicates the location of the R-band nucleus.

Radio triggered star formation models usually attribute the triggering mechanism to shock compression of cold clouds along the radio jets (Rees 1989; De Young 1989; 1995). However, the star formation in A1795 was apparently triggered along the edges of its radio lobes, rather than along the jets, where shock compression should be most effective. The cold material may have collected along the lobes, creating a gas overdensity that produced a locally enhanced region of star formation compared to the star formation that extends several kiloparsecs beyond the radio lobes with a Type 4 morphology. It is difficult to determine the fraction of the total star formation rate associated with the lobes because the amorphous population may have a different star formation history.

Assuming the entire population formed in a burst triggered less than 10 Myr ago, roughly half of the  $\sim 10^8 M_\odot$  of material involved in the burst could have been induced to form stars by the radio source (McNamara & O’Connell 1993). It would appear that the radio source is augmenting existing star formation, rather than triggering it outright. The situation is probably similar in NGC 1275 (McNamara et al. 1996b) and perhaps in A2597, although polarization measurements for these objects are not available. A lobe-like morphology (Figure 4) was recently discovered in the distant,  $z = 0.29$ , CDG Zw3146 (McNamara, Lotz & Mackie 1997). The lobes are not sufficiently resolved to determine whether they are physically distinct or are produced by a very large dust lane bisecting the nucleus. In addition, high resolution radio maps are not available for this object, whose radio luminosity is consistent with only an average FR I, while its cooling rate exceeds  $\sim 1000 M_\odot \text{ yr}^{-1}$  (Allen et al. 1992). Based on its  $H\alpha$  emission line luminosity, Zw3146’s star formation rate may approach  $\sim 100 M_\odot \text{ yr}^{-1}$ . The lobe structure in Zw3146 indicates that the blue-lobe phenomenon in cooling flows may occur frequently over a significant fraction of cluster ages. A high resolution radio image of this object is badly needed.

## 6. Disk Star Formation

The Type 2 morphology differs from the remaining types by the large angular momentum state of the accreted gas and stars. Type 2s are rare in cooling flows, but they are important. The Hydra A cluster central elliptical, which is the archetype for Type 2s, contains a blue, circumnuclear disk (Figure 5),  $8 \times 6$  arcsec in size ( $12 \times 9$  kiloparsecs;  $z = 0.055$ ,  $H_0 = 50 \text{ kms}^{-1} \text{ Mpc}^{-1}$ ) that is embedded in bright nebular emission in rotation about the nucleus (McNamara 1995; Hansen et al. 1995; Heckman et al. 1989; Baum et al. 1988). The blue population is confined to the disk, as is shown by the disk’s exponentially declining light profile indicating ordered stellar orbits. The Types 3 and 4 objects, in contrast, harbor a considerable amount of diffuse blue light, presumably from young, infalling stars on orbits with predominantly radial velocity components. Hydra A’s most striking property is the orientation of the radio jets nearly along the minor axis of the disk (see Figure 5). A twin-jet radio source is thought to be aligned with the minor axis (angular momentum axis) of a subparsec accretion disk surrounding a nuclear black hole (Rees 1984). The apparently aligned angular momentum axes of the putative subparsec and kiloparsec scale disks suggests they are coupled and may have formed simultaneously. Hydra A has long been a puzzle because its radio luminosity ( $P_{178} = 7 \times 10^{43} \text{ ergs s}^{-1}$ ) is an order of magnitude larger than most FR I radio sources (Ekers & Simkin 1983), perhaps by the provenance of the disk. The 21 cm line of atomic hydrogen has been detected in absorption through the disk against the radio source (Dwarakanath et al. 1995). Roughly  $\sim 10^{8-9} M_\odot$  of H I may be present over the face of the disk. Both the radio jet axis and the disk’s principal axes are misaligned with the principal photometric axes of the host galaxy, suggesting the gas was externally accreted. The origin of disk’s angular momentum is unknown. It is noteworthy that star formation was apparently not triggered by the radio source, in spite of Hydra A’s large radio power and dense intracluster medium (David et al. 1990), probably because the radio source has encountered little cold gas. In all likelihood, the nebular



emission traces the cold gas which remains close to the disk's orbital plane and away from the disk's polar regions where the jets are emerging. In contrast, the gas in Types 3 and 4 is widely distributed, and their radio sources have a high probability of colliding with gas clouds, resulting in distorted radio lobes, disrupted jets, and radio-triggered bursts of star formation.

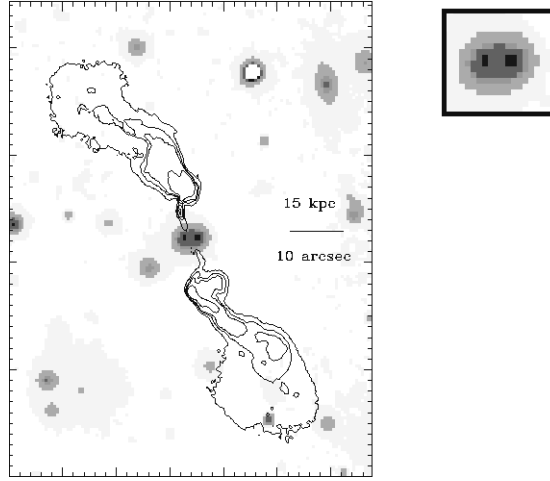


Figure 5: U-band map of the central disk (greyscale) in Hydra A after subtracting a model galactic background. An expanded view of the disk is inset to the upper right. The 6 cm radio map (contours) is superposed; the central radio core is omitted for clarity (McNamara 1995).

The ordered motion allows, in principle, a direct measurement of the total mass (disk + galaxy) encircled by the disk. The mass ratio of stars in the disk and underlying host galaxy can then be determined by modeling the background galaxy and photometrically decomposing the galaxy and disk. The dynamical and luminosity masses of the disk population can then be matched by adjusting  $\Upsilon_{\text{disk}}$ , thereby placing constraints on the IMF and dark mass. The required observations are best done with HST, but an analysis using ground-based observations indicates a mass of the young disk population to be  $\sim 10^8\text{--}9 M_{\odot}$ , or  $\sim 1\% \rightarrow 10\%$  of the total encircled mass (McNamara 1995). Existing ground based observations cannot be modeled precisely enough to infer useful information on the IMF.

## 7. An Evolutionary Sequence?

There is enough data on the structure of CDGs that one can begin to speculate on whether the structural types reflect an evolutionary sequence. In the simplest scenario, the CDG accretes  $\sim 10^8 M_{\odot}$  of material from a gas-rich dwarf galaxy or a cooling parcel of hot gas. This material sinks to the nucleus which generates an FR I radio source, followed shortly by a radio-triggered burst of star formation

fueled by the infalling gas. The initial result is a Type 3. The lobes quickly disperse in a few tens of Myr leading to a Type 4 morphology, while its color decays at the rate  $\frac{\Delta(U-B)}{\Delta \log t} \simeq 0.45$  magnitudes dex<sup>-1</sup> (c.f. Bruzual & Charlot 1993), and ends as a Type 1 in  $\sim$  Gyr. NGC 1275 in the Perseus cluster is an example of a CDG that may be in transition between Types 3 & 4 (see McNamara et al. 1996b). This evolutionary scenario may seem plausible based on the range of colors in Figure 1, and while I think there are aspects of this sketch that are probably true, it is too simple for several reasons. First, the blue lobe galaxies—Type 3s—are too prevalent. Of the 20 or so objects that have been imaged well enough to detect lobes, 2–4 are Type 3’s and there may be more lost to projection. The Type 3 phase should be brief; it represents  $< 1\%$  of the few Gyr lookback time of the available sample in Figure 1. If we are very lucky we should see one Type 3, barring some unknown selection effect (this sample was not selected on the basis of the radio properties). Therefore, radio triggered bursts must occur several times during the lifetimes of these galaxies, or they persist over long timescales which would be difficult to understand. For this to be so, the fueling must be frequent or persistent. There are other problems: Hydra A does not fit this scenario, and the few objects that have been studied in some detail (e.g. NGC 1275) seem to have stellar populations spanning a larger range of ages than one would expect from a single burst (see McNamara et al. 1996b for a recent discussion). In addition, the apparently continuous distribution of color excess when plotted against  $\dot{m}_{CF}$  suggests that the fueling is not entirely random, as one would expect for tidally triggered bursts, although some scatter in Figure 1 could be explained by periodic interruptions in the fuel supply by mergers, for example. Perhaps the rare Type 2s, Hydra A for example, show the high angular momentum signatures of tidal accretion, and perhaps not accretion from the cooling flow. Sensitive imaging at high resolution (e.g. Pinkney et al. 1996; Holtzman et al. 1996; McNamara et al. 1996a) of a large sample that includes a carefully selected control subsample of CDGs outside of cooling flows will be necessary to sort this out.

## 8. Concluding Remarks

It is clear that CDGs selected on the basis of residing in large cooling flows have unusual optical properties, and these properties are the result of gaseous accretion. Whether the hot gas is providing the cooling material that fuels the star formation, or whether the dense medium is promoting accretion from other sources—e.g. by providing a large cross section for ram pressure stripping of gaseous dwarf galaxies (McNamara et al. 1996a)—remains to be conclusively demonstrated. In my view the strongest evidence points to cooling flow accretion, but both processes are probably important (major mergers between galaxies are probably less important). The most vexing problem in cooling flows, the fate of most of the accreting mass, remains unsolved. I touched on two approaches for studying the IMF that may lead to progress with this question, but other approaches, such as the search for populations of low-mass stars in the infrared may be fruitful. We have not identified conclusively a CDG that formed out of a cooling flow. Zw3146 may be our best bet, but in general cooling flows are probably augmenting the mass of preexisting galaxies that grew, in part, by

mergers. What these objects are telling us about the evolution of ellipticals in general is most interesting. The blue lobe galaxies are important in this regard, because they may be related in some way to the distant, FR II radio galaxies showing the “alignment effect.” Many distant FR IIs have blue optical structure that is aligned with their radio sources, and likewise may be undergoing massive bursts of star formation at rates of  $\sim 100 M_{\odot} \text{ yr}^{-1}$  (McCarthy 1993). The situation is more complex in the FR II’s, whose radio-aligned optical continuum is often polarized (Jannuzi & Elston 1991). The polarized continuum appears to be light from an AGN that is beamed along the radio axis and scattered into the line of sight by dust or electrons. However, blue continuum from young stars may be a significant component (e.g. Stockton et al. 1996). A1795 may be a relatively nearby, lower luminosity, FR I counterpart that is dominated by starlight rather than scattered AGN light. Clearly the alignment effect is not the exclusive domain of FR II radio galaxies at high redshifts. Further progress in this area will be made using new, high spatial resolution imagery and spectra of CDGs in the ultraviolet, U, and infrared bands, and in the X-ray band with AXAF.

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